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HYDRAULIC MODEL STUDIES OF THE STILLING BASINS
FOR THE ENERGY ABSORBER DISCHARGES
AT POLE HILL AND FLATIRON POWER PLANTS
COLORADO - BIG THOMPSON PROJECT

Hydraulic Laboratories Report No. Hyd-353

ENGINEERING LABORATORIES BRANCH



DESIGN AND CONSTRUCTION DIVISION
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Engineering Laboratories Branch
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Laboratory Report No. Hyd-353
Hydraulic Laboratory
Compiled by: W. P. Simmons, Jr.
Checked and
reviewed by: W. C. Case and
J. W. Ball

Subject: Hydraulic model studies of the stilling basins for the energy absorber discharges at Pole Hill and Flatiron Power Plants--Colorado-Big Thompson Project

PURPOSE

To develop suitable stilling basins in the power-plant afterbays to distribute and quiet the discharge from the turbine by-pass energy absorbers to prevent erosion damage to the afterbay channels.

CONCLUSIONS

1. A stilling basin design consisting of a short channel about 9 feet wide by 8 feet deep with a sloping downstream end and two large transverse baffles inclined downstream 15° from the vertical will satisfactorily control the discharge from the energy absorbers at the Pole Hill and Flatiron Power Plants. (Figures 7H, 14, and 18D).
2. During by-pass operation the energy absorber flow will sweep the recommended stilling basins clear of debris.
3. The basin designs operate equally well at maximum and minimum tail-water depths.
4. There will be no pressure reduction on the basin floors sufficient to cause large uplift forces.
5. The discharge from the draft tube of the Pelton energy absorber for the Pole Hill and Flatiron turbine by-passes occurs with a distorted velocity front and contains large quantities of air which are required in the absorber to suppress cavitation damage. Both the distorted velocity front and the large amount of entrained air tend to produce rough flow in the power-plant afterbays (Figures 17 and 20).
6. The uniformity of the air-water mixture at the exit of the absorber draft tube affects the stilling basin operation. A reasonably uniform mixture across the passage, as is anticipated in both prototype structures, is better controlled by the basin than a nonuniform mixture with large amounts of air in the upper regions, as occurred in the models.

7. Scour should not be a consideration in the final prototype paved channel because almost no scour occurred on the loose pea-gravel that was used in the Pole Hill model to represent the rip-rapped channel of the preliminary design afterbay (Figure 9B).

8. A small, 45° deflector on the inside corner at the end of the left afterbay training wall of the Pole Hill structure (Figure 14) reduces the water velocities along the left afterbay channel bank.

9. The beam-supported transformer deck in the preliminary design, modified to include six 3-inch or larger vents through the beams to relieve any trapped air, is satisfactory for the Pole Hill structure (Figure 14).

10. The deflector mentioned in (8) is not required on the Flatiron Power Plant stilling basins.

11. Removal of the 90° elbow from the absorber draft tube results in a nearly uniform air-water mixture at the draft tube outlet, but in higher velocity concentration (Figure 19). The stilling basin performance with the straight-draft tube is better than with the tube having an elbow because the benefits derived from the improved air-water distribution more than offset the effect of the higher concentration of water velocities. However, since the manufacturer guaranteed the energy absorber-draft tube assembly as a unit design changes could not be made, and the straight-draft tube could not be used on the prototype structures.

RECOMMENDATIONS

1. Use the short, channel-like stilling basins with transverse baffles to distribute the discharge from the energy absorber draft tubes at the Pole Hill and Flatiron Power Plants (Figures 14 and 18D).

2. Use the 45° deflector on the inside edge at the end of the left afterbay training wall at the Pole Hill Plant (Figure 14).

3. Use the beam-supported transformer deck with air vents through the beams over the Pole Hill afterbay structure (Figure 14).

4. Consider a program to develop an energy absorber design that requires little or no air for the control of cavitation-erosion and has a "flat" velocity front at the draft tube exit. A satisfactory absorber design incorporating the above characteristics would find wide usage.

ACKNOWLEDGMENT

The recommended afterbay stilling basin design is the result of cooperative efforts of the Structural and Architectural Branch, the Canals Branch, and the Engineering Laboratories Branch of the office of the Chief Engineer in Denver.

INTRODUCTION

The Pole Hill and Flatiron Power Plants are incorporated in the Estes Park-Foothills Power Aqueduct, a part of the Colorado-Big Thompson Project in Colorado. The Pole Hill Plant is about 14 miles west of Loveland, Colorado. The Flatiron Plant is about 11 miles west of Loveland (Figure 1).

The main purpose of the Colorado-Big Thompson Project is to collect water from areas on the western slope of Colorado where the supply is abundant during the spring run-off, and divert this water at a uniform rate to the eastern slope of Colorado where the supply is short, (Figure 1). Water is collected from regions high in the mountains and after being transported under the Continental Divide through the Alva B. Adams Tunnel enters the Estes Park-Foothills Power Aqueduct. The aqueduct carries the water from elevation 8258 at the Adams Tunnel exit, to elevation 5430, the level of Horsetooth Reservoir. The elevation differences of 2,828 feet between the inlet and outlet of the aqueduct, combined with the quantity of water flowing, makes possible the realization of large quantities of hydroelectric power. Advantage is being taken of this possibility by including power plants along the aqueduct. Pole Hill and Flatiron are two of these plants, and they will operate under heads of 838 and 1,055 feet, respectively.

There may be occasions when the Pole Hill and Flatiron Plants do not operate because of small power demands. In order to not interfere with the normal delivery of water to the storage reservoirs and fields, provisions are made to pass the water either through or around the plants. At Pole Hill a diversion channel skirts the single unit plant (Figure 2). During the shutting down of the Pole Hill turbine, the flow must pass through the turbine by-pass. The by-pass can then be closed and the water diverted past the plant through a diversion channel. In the Flatiron structure, the flow will pass through the multiple unit plant, and when the turbine-generator units are not operating the water must pass continuously through the by-passes (Figure 3).

Past experience has shown that excessively rough flow conditions can occur in power-plant afterbays when by-passes are operated under high heads. When the operation is continued for extended periods, the currents and waves in the tailrace can inflict major damage to the riprapped channel surfaces. The turbulence in the afterbays during by-pass operation is mainly due to the poorly distributed flow discharged by the by-pass energy absorber-draft tubes. Previously conducted studies on a 1:4 scale model of the absorber type to be used at the Pole Hill and Flatiron Plants showed that velocities up to 40 fps would be expected in certain areas at the exit of the prototype draft tube, whereas the velocity would be zero or even reversed in direction in other areas (Report No. Hyd-348).

The studies discussed in this report were concerned with the development of stilling basins within the power-plant afterbays to distribute and quiet the rough flows from the absorbers and thereby produce smoother tailrace conditions. Scale models were built of the Pelton energy absorber and the Pole Hill and Flatiron afterbays to assist in the studies. The Pole Hill model was operated at conditions representing a discharge of 604 cfs, a head of 838 feet, and tail-water elevations ranging from 6580.0 to 6593.0 feet. The Flatiron model was operated at conditions representing a discharge of 475 cfs, a head of 1,055 feet, and tail-water elevations ranging from 5462.0 to 5472.8 feet. This report describes the hydraulic models and discusses the results obtained from the model tests.

INVESTIGATION

1:9 Model of the Pole Hill Afterbay

The 1:9 scale model represented the by-pass valve, the by-pass energy absorber, the power-plant afterbay structure, and about 90 feet of the excavated channel below the plant (Figures 4 and 5). The by-pass valve and absorber are discussed in detail later in this report. In the afterbay portion of the model, the vertical concrete wall forming the right side of the prototype power-plant afterbay and excavated channel (Figure 2) was represented by the side of the sheet-metal lined box which contained the model (Figure 4). The remainder of the afterbay structure was built of wood, and where necessary the wood was covered with sheet metal to make it waterproof. The invert and sloping left side of the excavated channel were formed in 1-1/4-inch gravel. Gravel was used throughout the tests to represent the material of the excavated channel even though field conditions later showed that a concrete lining was required to stabilize loose schist. The gravel was used to facilitate the study of scour conditions in the model. Water was supplied to the model by the laboratory system which contained Venturi meters for measuring the rate of flow. The static head of the water entering the by-pass needle valve was measured upstream from an elbow in the 3-inch pipe leading to the valve. Thus the loss for the elbow was added to the scale head for the reading at this point. By adjusting the 3-inch needle valve and the regulating gate in the 8-inch supply line, any combination of discharge and head could be obtained within the limits of the laboratory pumps. The tail-water elevation in the model was regulated by an adjustable tailgate at the downstream end of the model and was measured by a single-leg water manometer fitted with an appropriate scale. The water discharged freely from the end of the model and returned to the laboratory reservoir.

Flow Distribution at the Energy Absorber Draft Tube Exit

It was necessary to build a 1:9 scale model of the Pelton by-pass energy absorber to obtain flow in the model afterbay representing the

prototype mixture of air and water having the proper velocity distribution (Figure 5). The model included a needle valve to represent the by-pass needle valve, and an air inlet system through which air was measured and admitted to the absorber interior. This absorber requires air to prevent cavitation damage to its components. For the Pole Hill operating condition 8 percent air (ratio of free-air discharge to water discharge by volume) was required to just quiet (by ear) the cavitation in the model absorber. The absorber would take 12.5 percent air with the air inlet valve fully opened.

Water was supplied to the model at the rate of 2.48 cfs at an 82.4-foot static head measured at a point just upstream from the elbow in the 3-inch line (Figure 4). This value included the scale static head for the valve, 56.9 feet, and the bend loss $h_1 = 0.7 \frac{v^2}{2g} = 0.7 (36.4) =$

25.5 feet. The 56.9-foot static head at the valve entrance plus the velocity head of 36.4 feet in the 3-inch pipe produced a total model head of 93.3 feet of water. This was equivalent to the prototype Pole Hill head of 838 feet. The velocity distribution of the discharge leaving the model-draft tube was measured by pitot tube traverses in a vertical plane 4 inches upstream from the absorber-draft tube outlet (Figure 5). Three traverse stations were located in the plane; one on the model passage center line, and one on each side 3-1/2 inches from the center line. The flow occurred with high velocities across the width of the draft tube near the tube bottom and at the left and center traverses near the tube top. Low velocities were present in the middle of the center traverse and at the top of the right traverse (Figure 6). The flow pattern was somewhat unstable in the draft tube, particularly at the center traverse. This is partly attributed to the large volumes of air present in the flowing water. The instability of the flow made it difficult to duplicate readings at the center traverse and several tests were made at this station to establish the velocity profile for the given operating conditions. Two tests were made at each side station.

Velocities up to 9.3 fps were found in the model. This corresponds to a prototype velocity of $9.3 \times \sqrt{\text{scale ratio}} = 9.3 \times \sqrt{9} = 27.9$ fps for the Pole Hill structure. These velocities are somewhat lower than those indicated by tests on the 1:4 model, Report Hyd-348.

The pitot tube, when in position for making a traverse, was sensitive to direction in the horizontal plane and was rotated to place the total head opening directly into the flow by balancing the pressures in the two static legs. This directional sensitivity showed that the flow at the side traverses moved toward the center of the passage at the top of the draft tube (which corresponds to the inside of the elbow) and moved outward from the center at the bottom of the passage (which corresponds to the outside of the elbow). This is in accordance with the secondary flow circulation commonly found downstream from a conduit elbow. This secondary flow, combined with the large volumes of air in the flow, probably accounts for the unstable conditions at the center pitot tube station.

Stilling Basin for the Energy Absorber Discharge

No baffles--sloped end. The outlet of the energy absorber-draft tube was placed about 8 feet (prototype) lower than the outlets of the turbine draft tube (Figures 4 and 8A). This produced a basin approximately 8 feet deep by 9 feet wide in the invert of the afterbay structure. For the first test the end of this basin was sloped upward to meet the normal afterbay invert elevation at the downstream end of the apron (Figure 7A). Eight percent air was admitted to the absorber during this and all subsequent tests on the stilling basin for the Pole Hill energy absorber. This was the amount of air needed to just quiet (by ear) the cavitation in the model absorber. Flow in the afterbay was very turbulent with this basin design (Figure 8B). High water velocities and severe wave action were present at the end of the left power plant wall and on the left bank of the river channel. The scour that occurred in the channel can be judged by comparing the contours of the channel before the flow was started (Figure 8A) with the contours produced by a run of 2-1/2 hours at the maximum discharge and head, and with the minimum tail-water elevation of 6580.0 (Figure 9A).

No baffles--vertical end. The sloping end of the basin was replaced by a vertical wall placed near the downstream end of the afterbay floor (Figure 7B). This design brought the air-water mixture to the afterbay surface further upstream than the preliminary design, but in too violent a manner. In addition, rocks were carried into the end of the basin where they moved about to pound and batter the basin walls and floor.

Vertical, triangular baffles--vertical and sloping ends. Three vertical triangular baffles, similar to those used in the Flatiron Pump-Turbine by-pass structure (Report No. Hyd-328) were placed in the basin to break up the water stream and to help distribute the flow as it rose to the surface (Figure 7C). Greatly improved flow conditions were obtained. However, it appeared that better flow would result if the absorber discharge was brought to the surface further upstream in the afterbay. A cover was placed over the triangular baffles to accomplish this. The cover was the same width as the basin and extended from a point 4 inches downstream from the model draft tube outlet to the downstream corner of the side-wall baffles (Figure 7C). This design caused the water to rise violently to the surface near the afterbay head wall. When the upstream end of the cover was cut back to follow the sides of the upstream pier, the action was somewhat less violent but still not acceptable. The use of a cover over the baffles for this basin was abandoned.

The three baffles were moved so that the one farthest upstream was 4 inches from the model draft tube outlet. The relative spacing between the three baffles remained unchanged and no cover was used. This design produced good flow conditions in the afterbay. However,

rocks were carried into the basin where they remained to pound and grind the basin wall and floors. The tendency to collect and hold material was greatly reduced by replacing the vertical end wall with a 45° slope (Figure 7C). However, some of the larger material was still held in the eddies behind the side-wall baffles and it could not be swept out of the basin by the absorber flow. Thus the side-wall baffle eddies, which were fundamental in the stilling action of this over-all baffle design, prevented the basin-sweeping tendencies that were desired. The stilling basin investigation was therefore continued using other types of baffles.

Vertical, rectangular baffles--sloping end. Two rows of staggered, vertical, rectangular baffles were placed on the basin floor (Figure 7D). The upstream row of three baffles was placed 4 inches from the model draft tube outlet, and the downstream row of two baffles was placed 4 inches behind the first row. The toe of the 45° sloping basin end wall was 16.5 inches (model) from the draft tube outlet. The two rows of rectangular baffles exerted only slight control on the flow and the afterbay conditions were similar to the conditions obtained without baffles. To assist the baffles in diverting the water upward, a deflector was placed across the basin floor immediately downstream from the draft tube outlet. This deflector, in cross section, formed an isosceles triangle 1-1/2 inches high. The effect of the deflector was too severe and the flow was turned upward so that it passed over the end of the chute in a nearly unbroken stream and produced an extremely rough water surface. Studies on other similar deflectors did not appear to be justified.

Four transverse baffles--sloping end. Attempts were made to bring the flowing air-water mixture to the afterbay surface by "peeling off" layers of the stream and directing them upward by means of horizontal transverse baffles. Four baffles were used in the first test (Figure 7E). The sloping basin end was retained because of its favorable debris-sweeping characteristics. Good flow conditions were obtained in the afterbay with this basin design. However, more water was needed under the downstream baffle to help the basin-sweeping action. In subsequent designs this additional flow was obtained by placing the downstream baffle higher above the basin floor.

Three transverse baffles--sloping end. For reasons of simplicity, lower cost, and structural strength, fewer but larger baffles appeared desirable. Accordingly, three larger baffles (Figure 7F) were tried with good results.

Two transverse baffles, inclined 15° --sloping end Two baffles were also tried (Figure 7G). These were tipped downstream 15° from the vertical position to produce converging passages between the beams and the floor and thereby lessen the danger of subatmospheric pressures along the lower upstream baffle corners. Considerable flow

was permitted under the downstream baffle. The slope at the end of the chute was reduced to about 39° to aid in sweeping rocks from the basin. Moderately good flow was obtained.

Recommended design. Other tests showed that the flow could be improved by increasing the height of the 4-inch model baffles to 6 inches (Figures 7H and 10). The higher baffles produced afterbay flow conditions as good or better than those obtained with the three triangular baffles and afforded greatly improved tendencies for keeping the basin clear of debris. Scour tests made with the high baffles in the basin and pea-gravel instead of 1-1/2 gravel in the upstream end of the excavated channel showed that almost no scour occurred (Figure 9B). Changes in tail-water elevation from less than the minimum at elevation 6580.0 up to the maximum at elevation 6593.0 showed that the basin was insensitive to tail-water depth.

New baffles were constructed of rib-reinforced 1/8-inch-thick sheet metal (Figure 11). Each baffle was provided with nine 1/8-inch-diameter piezometers. A single pressure cell was used for detecting the transient piezometric pressures and the pressure cell signals were recorded with an oscillograph. The pressures on the baffles were above atmospheric at all operating conditions including operation at the model equivalents of the maximum discharge of 604 cfs, an 838-foot head and the minimum tail-water elevation of 6580.0 feet. The oscillograph traces reproduced in Figures 12 and 13 are for this condition. The elevation of the basin floor is represented by the solid line near the bottom of the traces. The elevation of each individual piezometer is represented by the dashed line on the trace for that particular piezometer. The distance between the dashed line and the pressure cell trace represents the pressure at the piezometer. A scale is given on the figures so the actual values can be determined. The loads imposed on the baffles by the flowing water can be approximated from these pressure measurements. On the upstream baffle, which is subjected to the most severe conditions, the maximum model pressure at the center of the upstream face (piezometer 2) is 6.0 feet of water. At the center of the downstream face (piezometer 7) the minimum pressure is 3.3 feet of water. The difference of 2.7 feet, multiplied by the value of the ratio of the prototype to the model (9) gives the maximum prototype pressure differential of 24.3 feet of water between the centers of the upstream and downstream faces of the baffle. Other representative loads can be determined in a similar manner. The rapidity of pressure fluctuations can be determined by means of the time-lines included on the oscillograph traces. The space between each fine line represents 0.01 seconds, and space between the heavier lines represents 0.1 seconds.

The baffle design was considered satisfactory for use in the prototype structure because the pressures on all the surfaces were positive and because the baffle loads were not excessive. The overall basin and baffle design shown in Figure 7H and 14 is therefore

recommended for the Pole Hill afterbay structure. Model studies indicated that minor changes in the baffle locations (2 feet up or downstream) were permissible in the prototype structure in order to avoid construction joints.

Afterbay Training Wall Deflector

The water within the confines of the concrete afterbay structure, due to its vertical velocity and to its decreased density because of entrained air, had a higher surface than the water in the excavated channel downstream. Thus when the water entered the channel from the concrete structure there was a tendency for the flow to spread sideways as well as downstream. This tendency was small when the recommended stilling basin was used, but persisted to some extent. Efforts were made to reduce the tendency of the water to spread to the left side because of the desirability to reduce the water velocities to a minimum along the left channel bank. The spreading was reduced by placing a small, 45° deflector on the inside edge at the end of the left afterbay training wall (Figures 10 and 14). This deflector is recommended for the field structure.

Transformer Deck Interference

Beam-supported deck. The transformers of the Pole Hill Power Plant will be mounted on a deck that extends over the afterbay structure. This deck, in the preliminary design, was supported by large beams, the lower portions of which were submerged when the tail water was at the maximum elevation (Figure 14). It appeared that these beams would interfere with the flow at high tail-water elevations and form an air trap. Model tests showed that the beams did interfere with the flow, although not as much as was expected; and that air did collect in the space between the two deep beams. The air pressure build-up was limited, however, because upon reaching 0.07 feet of water (model) the pressure was relieved when some of the air escaped to the atmosphere.

Flat-slab deck. To lessen the flow interference and the air entrapment a deck was proposed which consisted of a thick reinforced concrete slab with a flat undersurface at elevation 6594.25; the highest elevation that was economically feasible for the structure. This height was found to be not great enough to clear the boil caused by the air-water mixture rising to the surface. As a result the flat slab interfered with the flow more than the beam-supported deck and produced excessive disturbances in the openings for the draft tube closure gates. These openings are shown in Figure 14 for the beam-supported deck.

Recommended deck. The relatively minor flow interferences produced by the beam-supported transformer deck, and the fact that the maximum tail water can occur only during an extreme flood, led

to the conclusion that the beamed deck was satisfactory for the prototype structure provided the air trap was vented. The beam-supported deck with six 3-inch or larger vents through the two deep beams to permit the continual escape of air from between the beams is therefore recommended for the field structure (Figure 14).

The above completed the studies of the stilling basin for the energy absorber discharge at Pole Hill Power Plant.

1:8.8 Model of the Flatiron Afterbay

After the completion of the Pole Hill studies the afterbay portion of the model (Figure 15A) was modified to approximately represent, at a 1:8.8 scale, the central portion of the Flatiron Power Plant afterbay (Figures 15B and 16). The central portion, rather than the left side of the afterbay, was chosen because stilling basin there would be unconfined whereas the basin at the left of the afterbay would be partially confined and therefore somewhat similar to the previously tested Pole Hill basin. The energy absorber was used without change and the 1:8.8 scale was determined by the ratio of the 10.33-inch exit width of the model draft tube to the 91-inch exit width of the prototype draft tube. The 8-inch exit height of the model draft tube was less than the equivalent 8.67-inch height of the prototype tube and this discrepancy resulted in higher than equivalent water velocities entering the model basin. The discrepancy was permitted because the true flow conditions would be satisfactory if these more severe conditions could be controlled.

The Flow in the Afterbay

The first model tests were made using the same stilling basin and baffles that were used in the recommended Pole Hill design (Figures 7H and 14) and with a flow equivalent to the 475 cfs prototype discharge at a 1,055-foot head and with the minimum tail-water elevation of 5462.0. The flow in the afterbay was rough at the head wall due to the air-water mixture rising to the afterbay surface farther upstream than it did in the Pole Hill model. The difference between the way the air-water mixture rose to the surface in the Flatiron afterbay and in the way it rose in the Pole Hill afterbay was due to the absence of a training wall next to the stilling basin on the Flatiron structure and to a less uniform air-water mixture at the draft tube exit. The cause and influence of the difference in the air-water mixture is discussed later in this report. The water surface, which was rough at the afterbay head wall, smoothed out rapidly as the water moved downstream and only a few small waves remained when the water neared the end of the paved channel.

The amount of air supplied to the model absorber directly influenced the amount of disturbance in the afterbay with the disturbance increasing as the air supply was increased. The effect

of the air is shown in the photographs in Figures 17A, B, and C for the conditions when no air, 9 percent air, and 18 percent air by volume, respectively, were supplied to the absorber. The water discharge and the head on the by-pass valve were maintained at model values equivalent to the maximum prototype discharge of 475 cfs at a head of 1,055 feet and the minimum tail-water elevation of 5462.0. The 9 percent quantity of air is that quantity required to just quiet (by ear) the cavitation in the model absorber at these operating conditions. The 18-percent quantity is the maximum amount the absorber would take with the air inlet valve fully opened. These air quantities are higher than those obtained for the Pole Hill model mainly because of the greater head at which the Flatiron model operated.

Air Entrainment and Separation within the Absorber-Draft Tube Assembly

The pronounced effect of the quantity of air supplied to the absorber upon the afterbay flow conditions is due to the distribution of the air-water mixture as it discharges out of the absorber draft tube. This mixture distribution is in turn governed by the flow conditions within the absorber. The sizes of the air bubbles created in an air-water mixing process depend largely upon the velocity at which the water enters the mixing region. In this case the velocity is a function of the head differential across the by-pass valve. As the head is increased the water velocity is increased and smaller air bubbles are created. Each small bubble has only slight buoyancy and it exhibits little tendency to rise through the water. In the cone and bowl assembly inside the absorber (Figure 5) where the air first mixes with the water the high entering water velocity and the ensuing turbulence create a uniform air-water mixture in which most of the air bubbles are small. When the air-water mixture moves out of the bowl assembly and into the large diameter draft tube the extreme water velocities and turbulences diminish. At some downstream point the turbulence decreases to the extent that the natural tendency of the bubbles to gather into fewer and larger bubbles occurs and buoyancy becomes a predominant force aiding air separation. This separation continues while the flow moves through the absorber draft tube.

Another influence which tends to promote air separation is present in the 90° elbow at the draft tube entrance (Figure 5). As the flow moves around this elbow centrifugal force moves the water toward the outside (bottom) of the bend while the air, being less dense, moves toward the inside (top). This results in a concentration of air at the top of the draft tube passage.

By the time the flow reaches the draft tube exit the combined effects of the centrifugal action and the buoyant rise produces considerable more air in the upper half of the passage than in the lower half. When this concentration of air is discharged into the afterbay the buoyancy of the air and the action of the upstream stilling basin baffle quickly overcome the almost negligible momentum of the air in the horizontal direction. The air then rises rapidly through the tail water near the

afterbay head wall, and a large boil results at the water surface. The size of the boil increases or decreases with increases or decreases in the supply of air.

The amount of air which is able to separate from the water in the draft tube is influenced by the rate of rise of the air bubbles. If a given rate of rise is assumed, the amount of air which will separate from the water (up to the maximum amount of free air in the mixture) depends upon how long the separation is allowed to continue. The time available within the absorber depends upon the velocity of the flow through the absorber. This in turn depends primarily upon the rate of water discharge. Less water (2.06 cfs) was required in the Flatiron tests than in the Pole Hill tests (2.48 cfs) and thus more time was available for separation in the Flatiron tests. This is believed to be a contributing reason why, when a given percentage of air was admitted, more air separation occurred in the Flatiron tests than in the Pole Hill tests.

An important consideration concerning air entrainment and subsequent partial separation is that air entrainment cannot be accurately represented in the usual scale model. Air entrainment is very greatly affected by the operating heads (velocities) and the air separation depends upon the actual turbulences, velocities, and time intervals applicable to the particular structure. The model studies, which used heads of about one-ninth prototype, and water velocities of about one-third prototype, probably had too little air entrainment and mixing, and too much air separation. The prototype operation is expected to occur with a much more uniform air-water mixture at the basin entrance than was obtained in the model with the result that the prototype afterbay will be relatively smoother at the afterbay head wall than indicated by the model. A large portion of the prototype afterbay will be white and foamy during by-pass operation due to the large volume of air entrained in the water in the form of small, slowly rising bubbles.

Attempts to Minimize the Effect of Air on the Afterbay Water Surface

Baffles inclined 30°. Regardless of the fact that the prototype absorber discharge is expected to be more uniform in air-water distribution than the model discharge changes were made in the baffles of the model stilling basin in attempts to minimize the tendency for the air to roughen the flow at the afterbay head wall. An increase in the slope of the baffles from the original 15° to 30° (Figure 18A) had little or no effect on the flow.

Downstream baffle only--inclined 15°. The removal of the upstream baffle, while retaining the original 15° downstream baffle, (Figure 18B), permitted the air-water mixture to surface farther downstream with the result that the water surface at the afterbay head wall was smoother, but the water surface near the end of the lined basin and the

entrance to the riprapped channel was rougher. In addition, the surface boil was erratic in both intensity and location.

Two baffles inclined 15° --upstream one raised. Reinstalling the upstream baffle at a 15° angle, but at a higher elevation (Figure 18C), resulted in flow similar to that with the original (Pole Hill) baffle design (Figure 18D). A repeat run with the baffles in the original position reaffirmed these results.

Recommended design. An appraisal of the flow in the afterbay led to the conclusion that although the water surface in the upstream part of the afterbay was rougher than desired, no damage would occur to the power plant or to any portion of the paved channel. Likewise no damage would occur in the riprapped channel below the paved section because the water surface was relatively quiet in this area and no swift currents or large eddies existed. Thus, it was decided that basins similar to the Pole Hill basin design would be satisfactory on the Flatiron structure and this basin design is therefore recommended (Figure 18D).

Pressures on the Stilling Basin Floor

Pressures were measured on the center line of the horizontal basin floor at points 2 inches and 15 inches (model) downstream from the draft tube outlet (Figure 18D). These pressures were found to be approximately equal to the depth of the water above the floor. The upstream pressure was slightly less than the downstream. The amount of air admitted to the absorber affected the pressures in such a way that the pressures decreased slightly as the air supply was increased. The floor pressures, expressed as equivalent water surface elevations, are given in Table 1 for operation with the model equivalents of the full 475 cfs discharge and 1,055-foot head and the minimum tail-water elevation of 5462.0 feet.

Table 1

<u>Piezometer</u>	<u>No Air</u>	<u>9 percent air</u>	<u>18 percent air</u>
1	5462.6	5461.8	5461.0
2	5463.4	5462.7	5462.5

These pressures show that no large uplift forces will occur on the basin floor due to flow conditions.

Effect of Removing the Elbow from the Absorber Draft Tube

To determine if improved flow characteristics would be realized by omitting the elbow from the draft tube, the 90° bend was removed from the model. The cone and bowl assembly was placed directly on the upstream end of the diverging portion of the tube (Figure 19). For a given set of operating conditions there was considerably less air demand with the modified draft tube than with the original one. This

was attributed to the greater back pressure acting on the valve and on the cone and bowl assembly due to their being located more deeply under the afterbay water surface. At the equivalent Pole Hill operating conditions of 604 cfs, an 838-foot head, and the minimum tail water, the maximum quantity of air taken through the air inlet system was 8.3 percent. Originally the absorber took 12.5 percent. Velocity traverses were obtained by means of a pitot tube at the same stations used for the traverses on the draft tube containing the bend. These traverses showed that a high-velocity stream moved along the center line of the tube and that relatively low-velocity flow occurred near the tube walls (Figure 19). This velocity distribution was far different from the desired uniform distribution. The velocity distribution of the center traverse was also measured when no air was supplied to the absorber. The distribution was found to be of the same general shape as the distribution with air present, but of generally lower velocities (Figure 19B).

During operations with air in the absorber, visual examination of the flow as it entered the stilling basin showed that the air-water mixture was nearly uniform across the draft-tube exit. As a result the stilling basin was effective in distributing and quieting the flow, and the afterbay flow conditions were not greatly changed by shutting off the air, (Figures 20, A and B). Apparently air has less effect upon the flow distribution through the absorber draft tube and upon the afterbay flow conditions when the elbow is omitted from the absorber draft tube.

Examination of the velocity profiles shown in Figures 6 and 19 leads to the conclusion that the 90° elbow, as placed in the original absorber draft tube (Figure 5), appreciably reduces the velocity concentration; but tends to increase the separation of air from the water. From the point of view of obtaining quiet flow in the afterbay the straight draft tube is better than the one with the 90° elbow because the benefits derived from the improved air-water mixture distribution are greater than the detrimental effects of the higher flow velocities.

FIGURE 1
REPORT HYD. 353

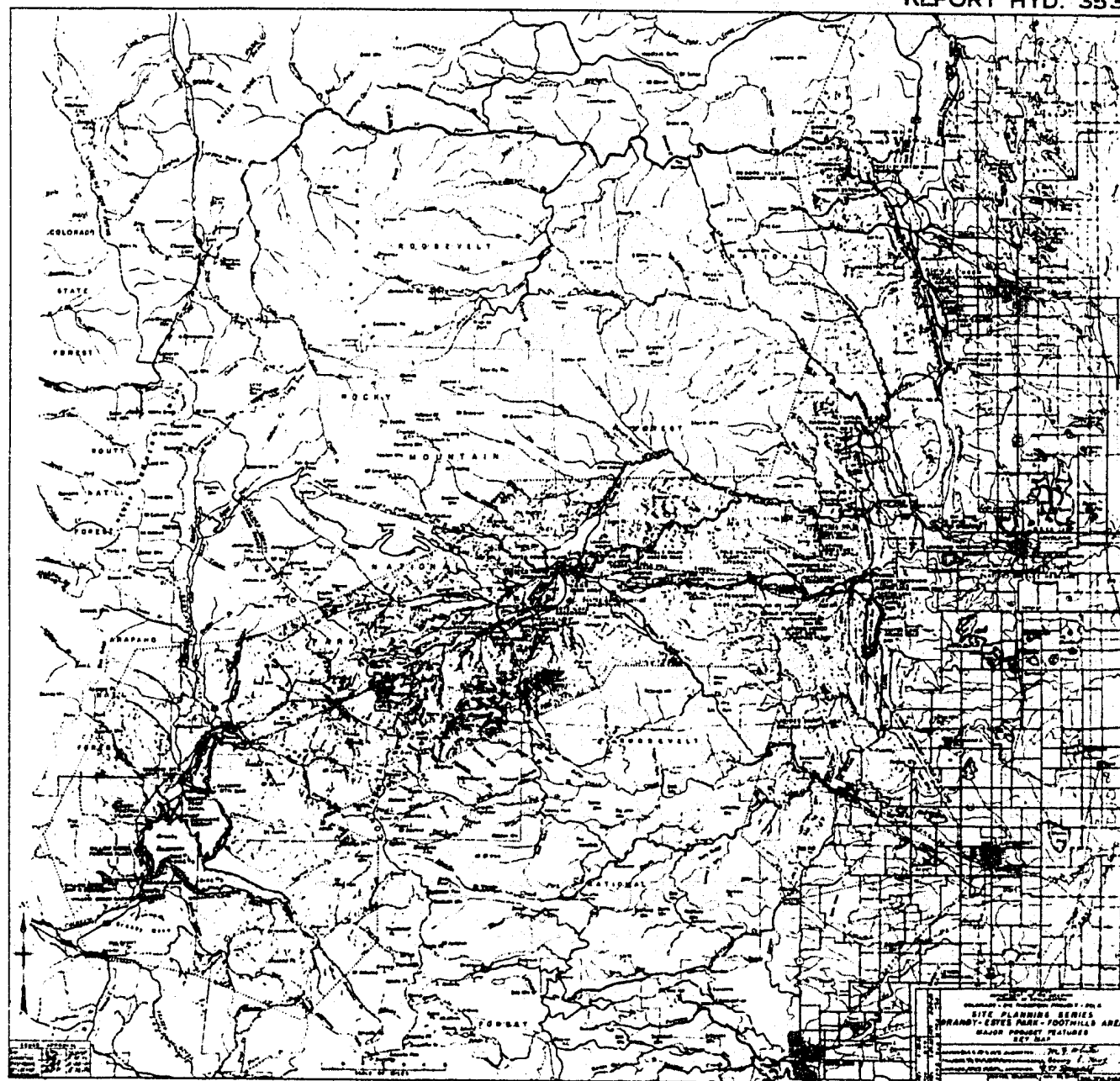
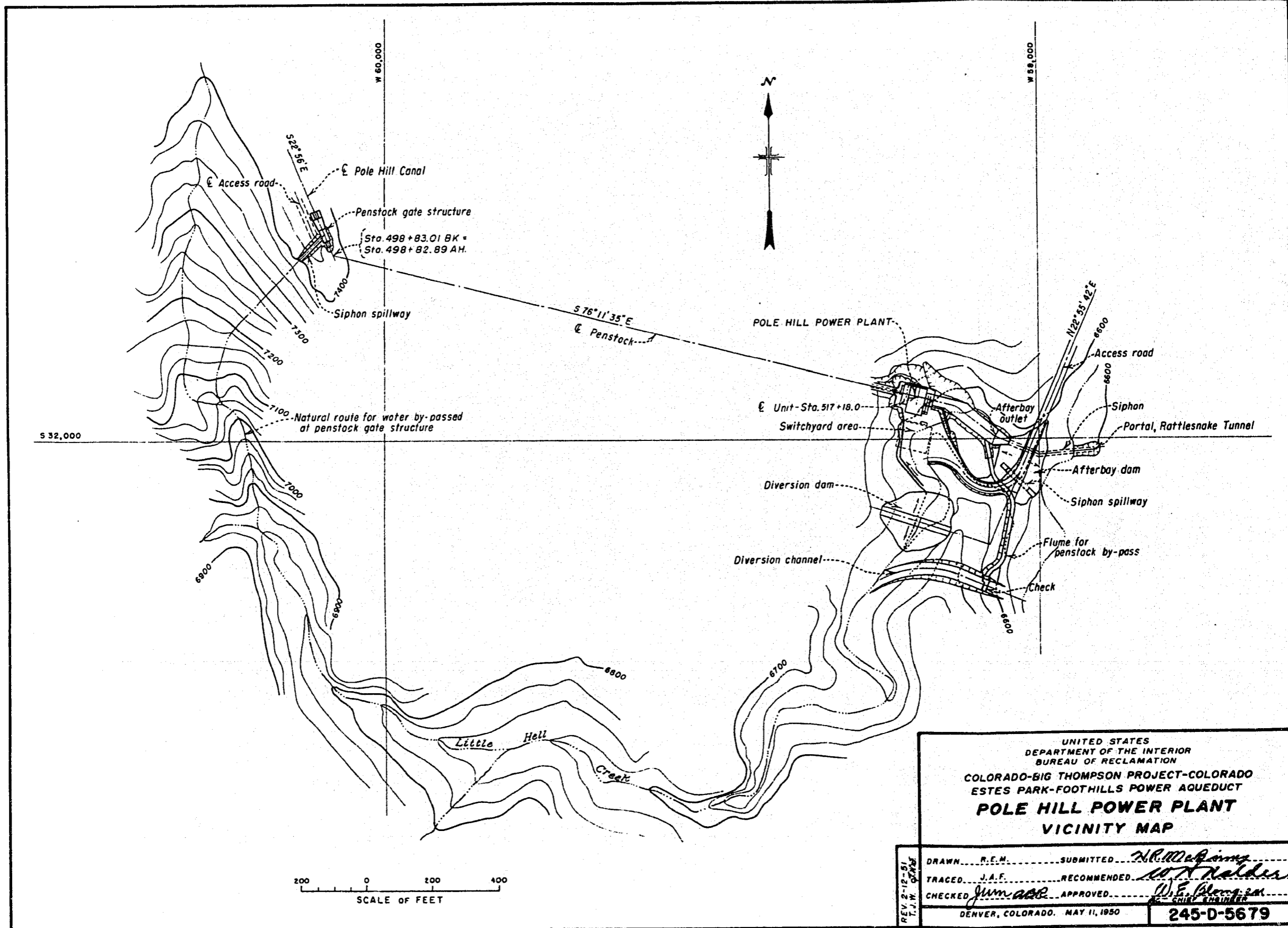
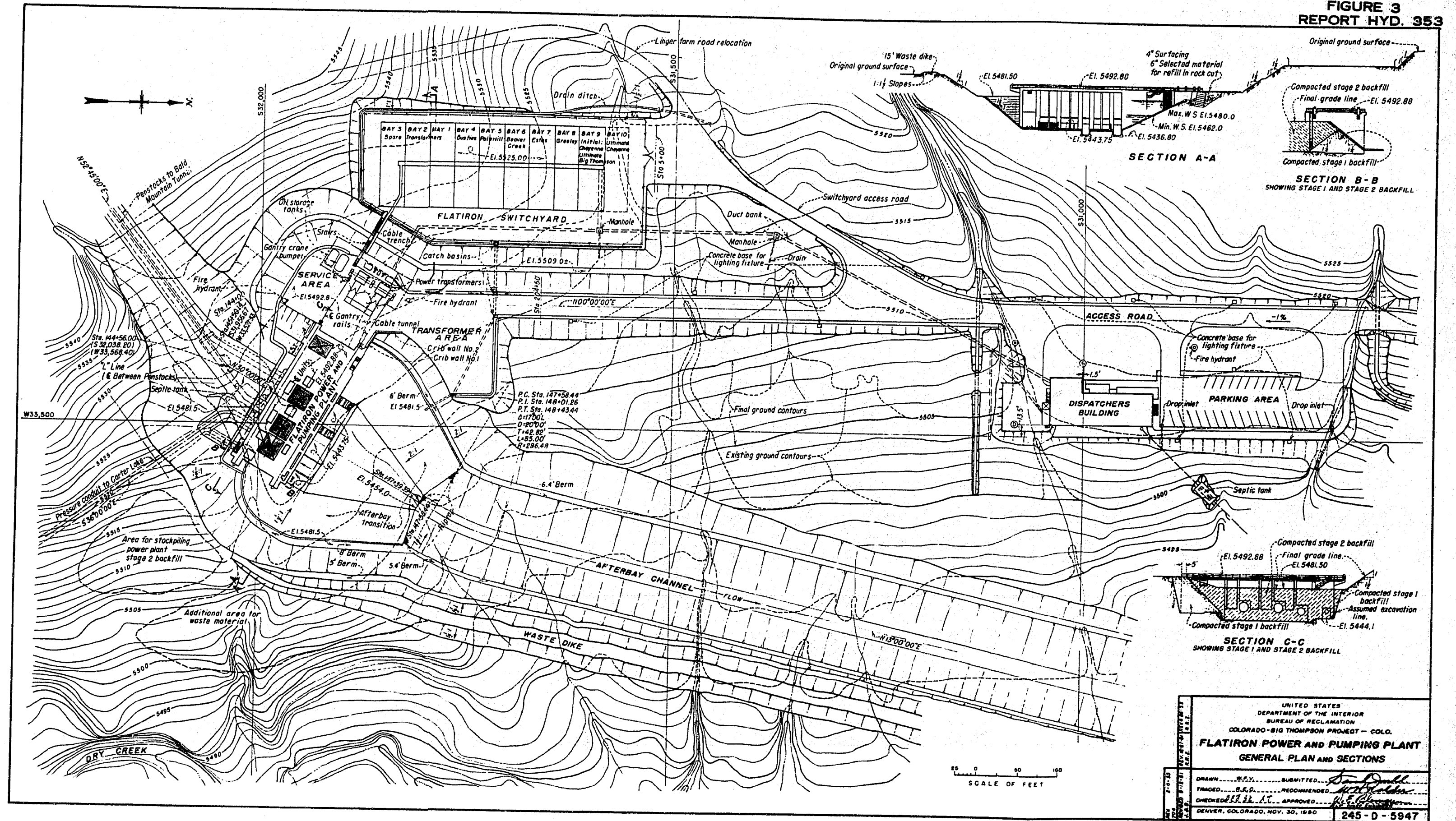


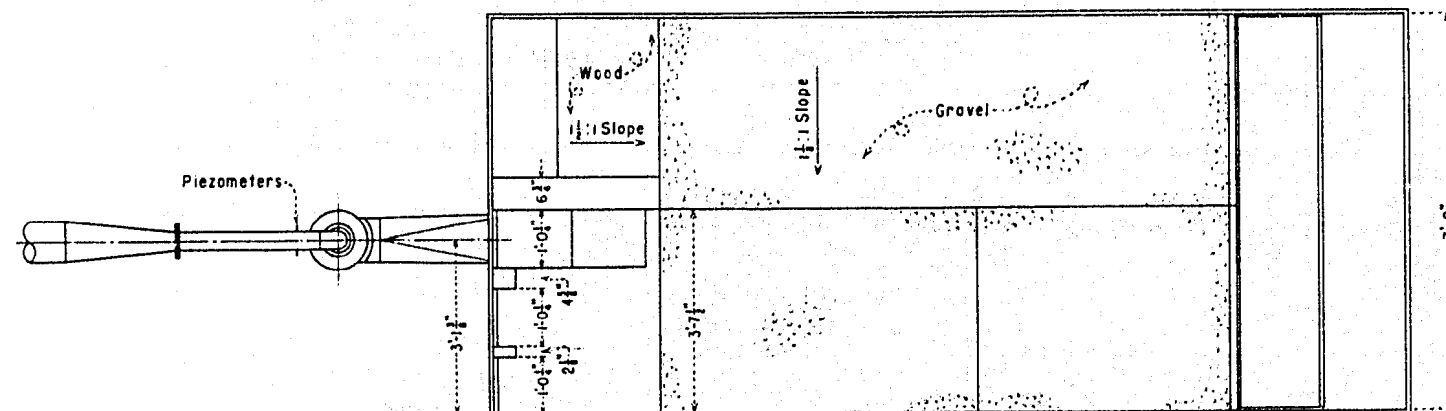
FIGURE 2
REPORT HYD. 353



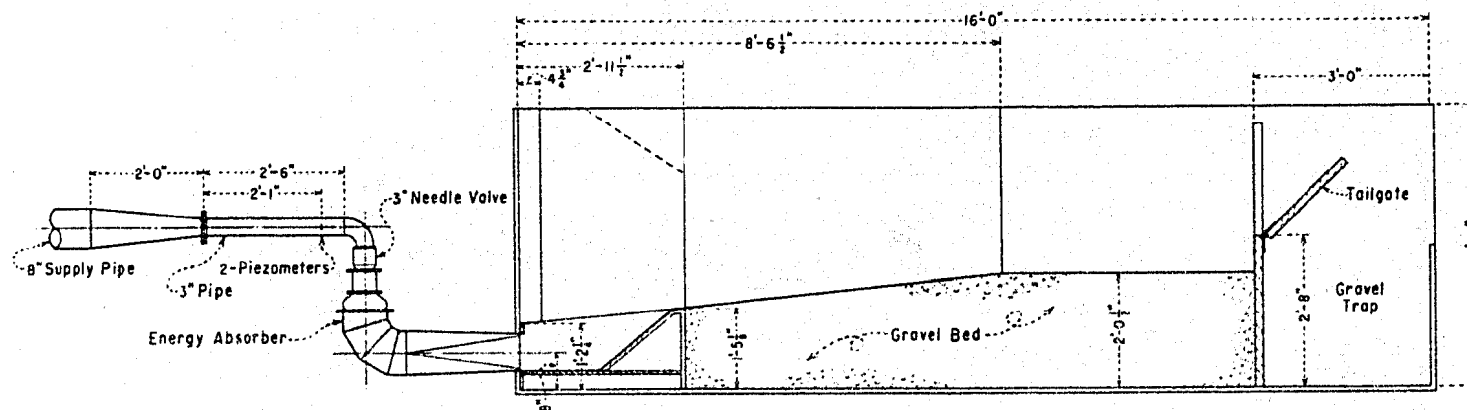
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION			
COLORADO-BIG THOMPSON PROJECT-COLORADO ESTES PARK-FOOTHILLS POWER AQUEDUCT			
POLE HILL POWER PLANT VICINITY MAP			
REV. 2-12-51 T. J. W. GARY	DRAWN.....	R. E. M.	SUBMITTED.....
	TRACED.....	J. A. F.	RECOMMENDED.....
	CHECKED.....	J. M. G. G.	APPROVED.....
	DENVER, COLORADO. MAY 11, 1950		245-D-5679

FIGURE 3
REPORT HYD. 353





PLAN

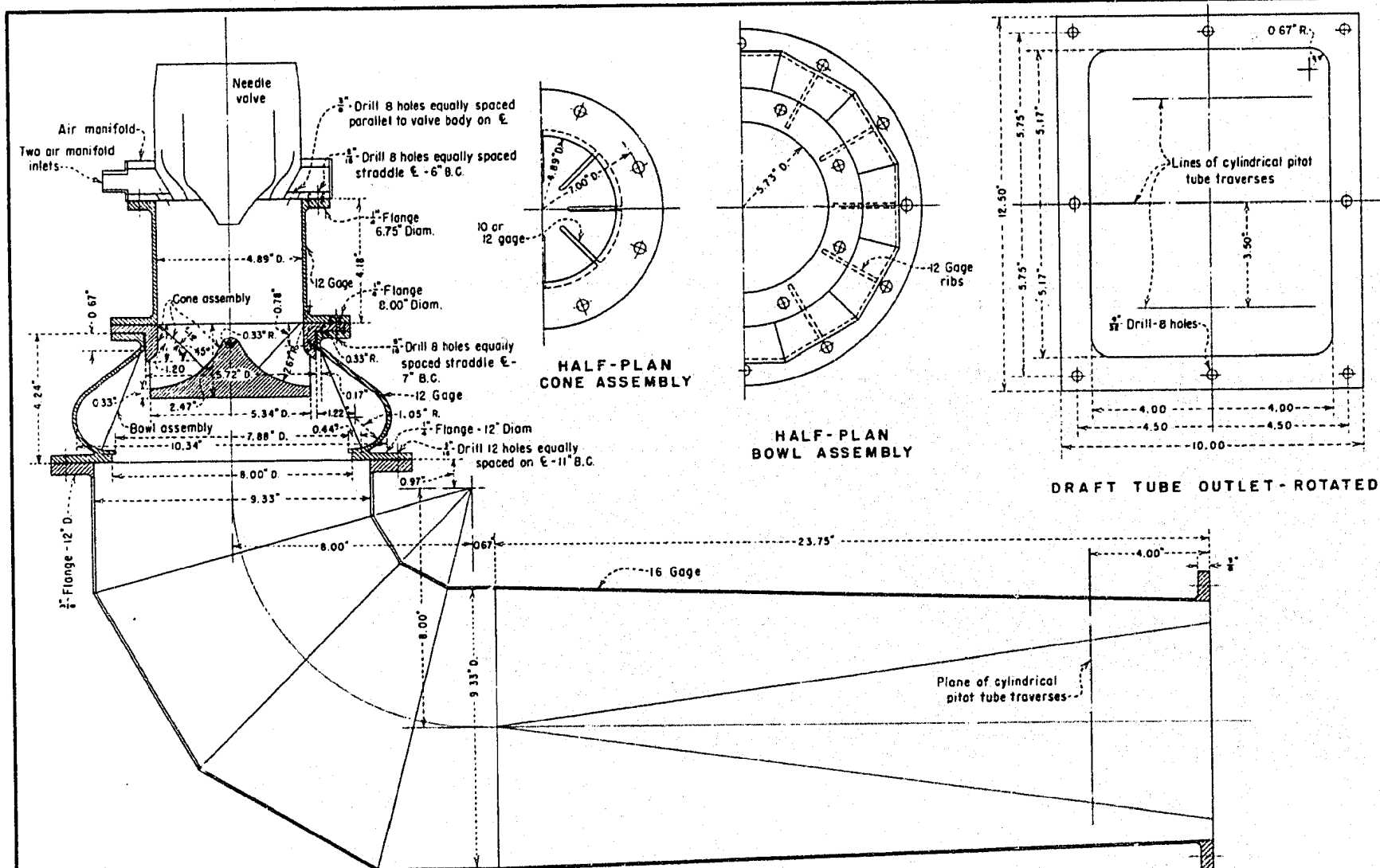


ELEVATION

STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER POLE HILL POWER PLANT

SCHEMATIC DIAGRAM OF THE LABORATORY MODEL

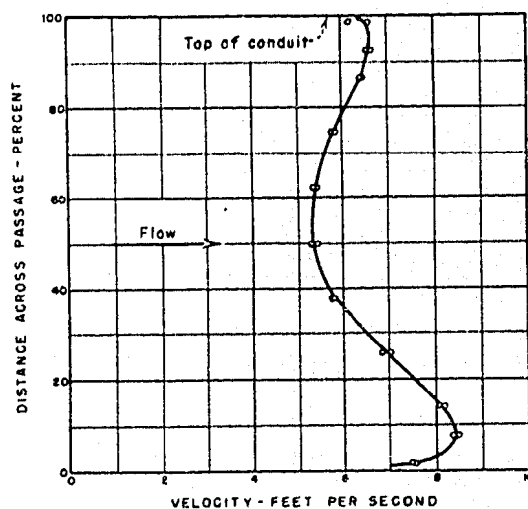
1:9 SCALE MODEL



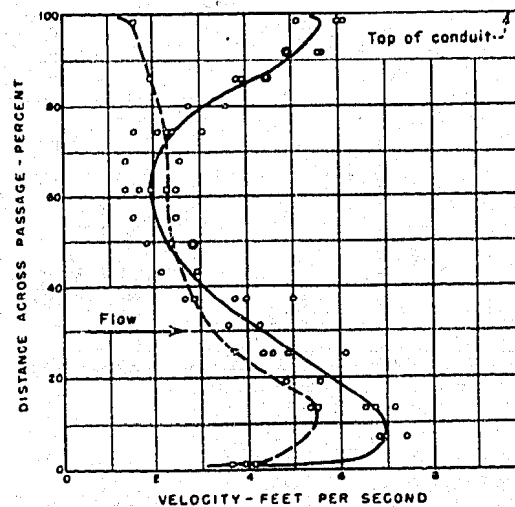
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBERS
POLE HILL AND FLATIRON POWER PLANTS

PELTON ENERGY ABSORBER

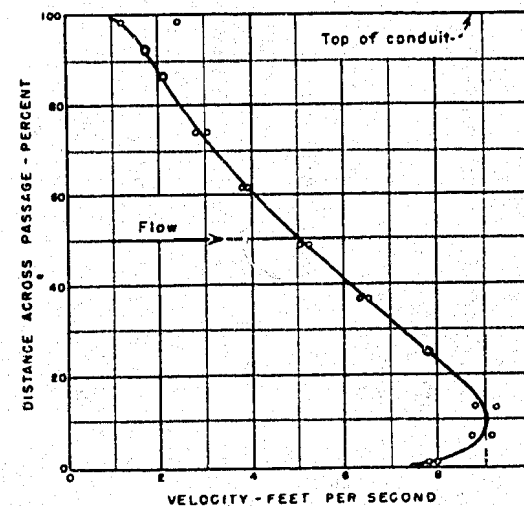
1:9 AND 1:8.8 SCALE MODELS



A. LEFT TRAVERSE

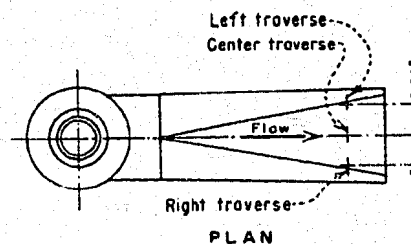
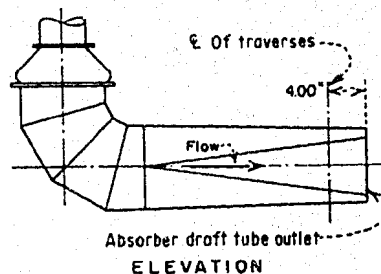


B. CENTER TRAVERSE



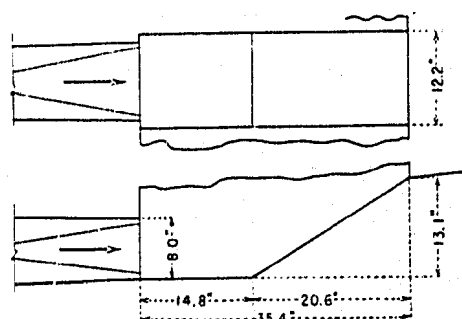
C. RIGHT TRAVERSE

—○— Full air admitted to absorber (12.5%)
 - - -○- - - No air admitted to absorber

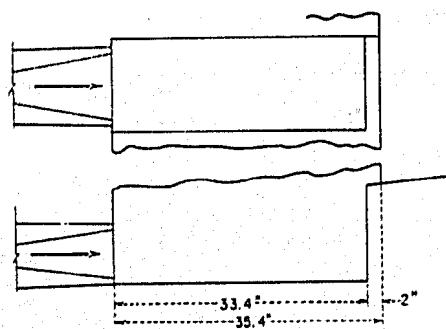


$Q = 604$ cfs (prototype)
 $H_T = 838$ feet (prototype)
 $T.W = 6580.0$ feet (prototype)

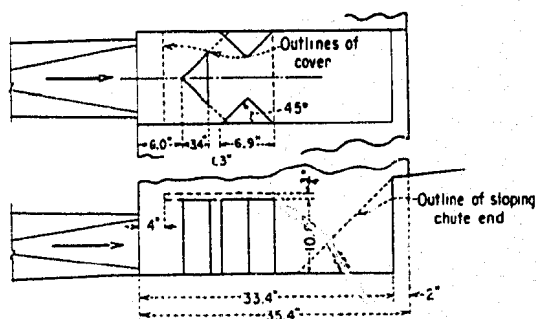
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
 POLE HILL POWER PLANT
 VELOCITY DISTRIBUTION AT THE EXIT OF THE ABSORBER DRAFT TUBE WITH ELBOW
 1:9 SCALE MODEL



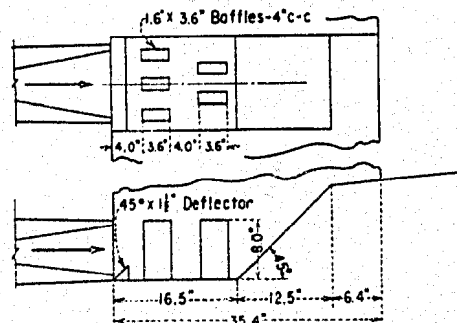
A. BASIN WITHOUT BAFFLES AND WITH SLOPED END



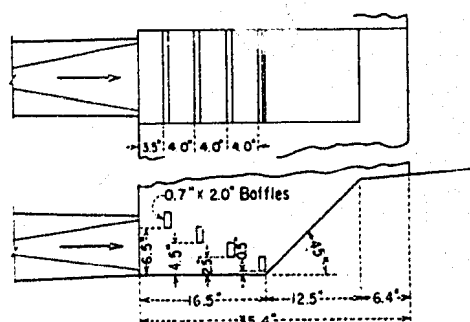
B. BASIN WITHOUT BAFFLES AND WITH VERTICAL END



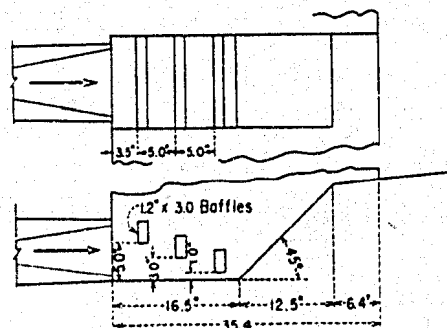
C. TRIANGULAR BAFFLES AND COVER-VERTICAL BASIN END



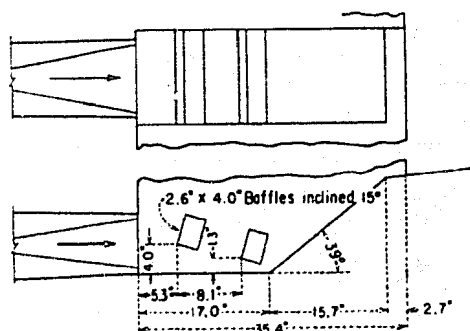
D. RECTANGULAR BAFFLES-SLOPED BASIN END



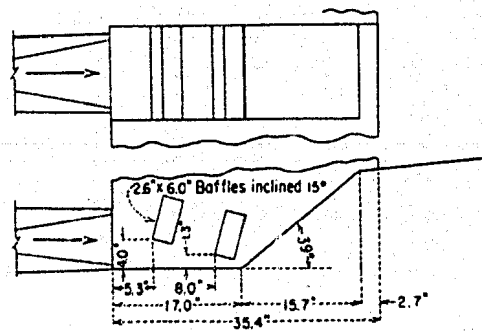
E. FOUR TRANSVERSE BAFFLES-SLOPED BASIN END



F. THREE TRANSVERSE BAFFLES-SLOPED BASIN END

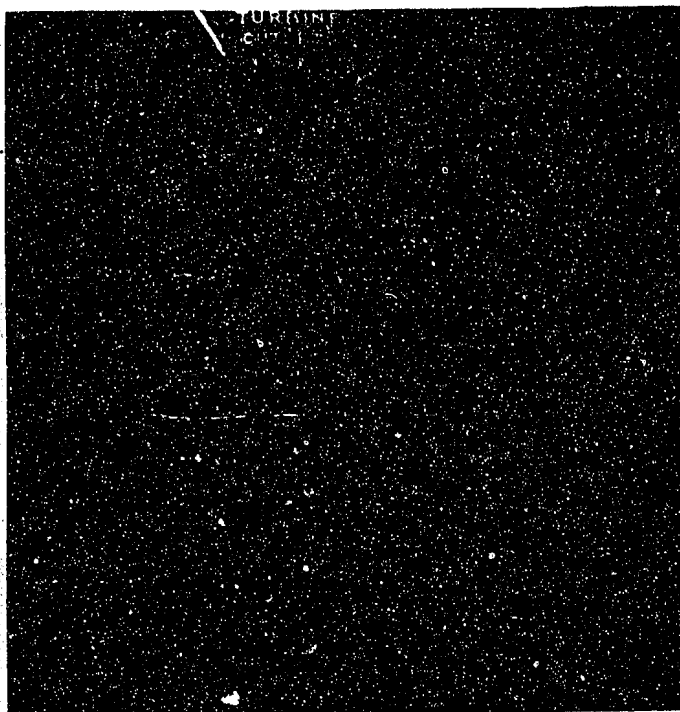


G. TWO TRANSVERSE BAFFLES-SLOPED BASIN END

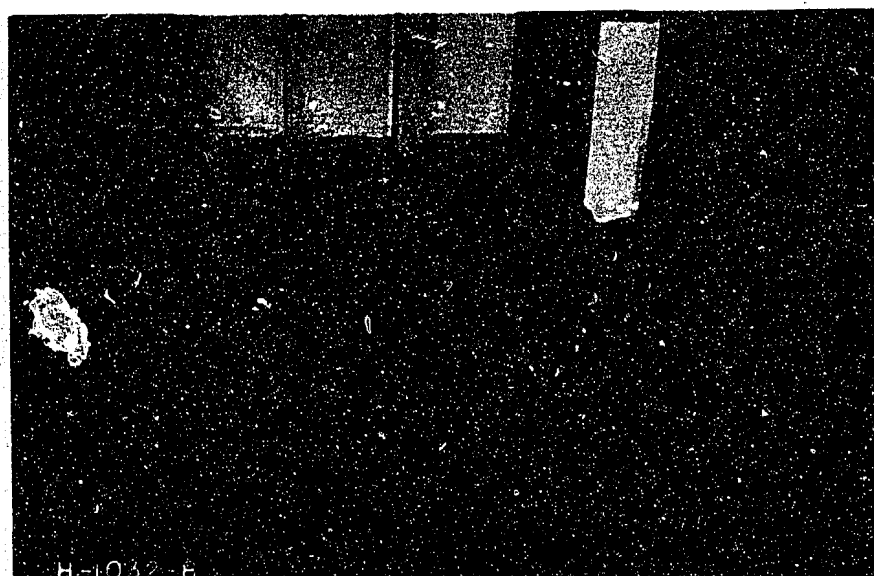


H. RECOMMENDED DESIGN-TWO TRANSVERSE BAFFLES-SLOPED BASIN END

STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT
STILLING BASIN DESIGNS TESTED
1:9 SCALE MODEL

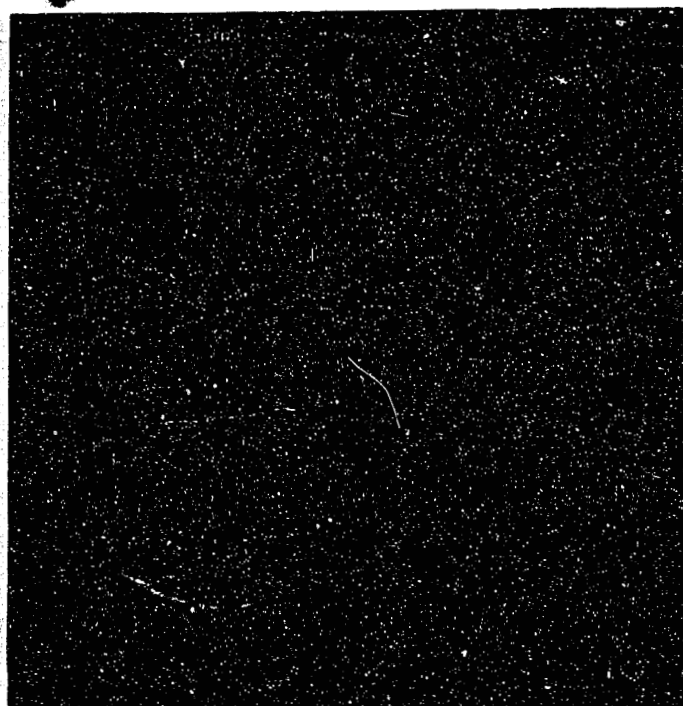


(A) The afterbay before scour tests

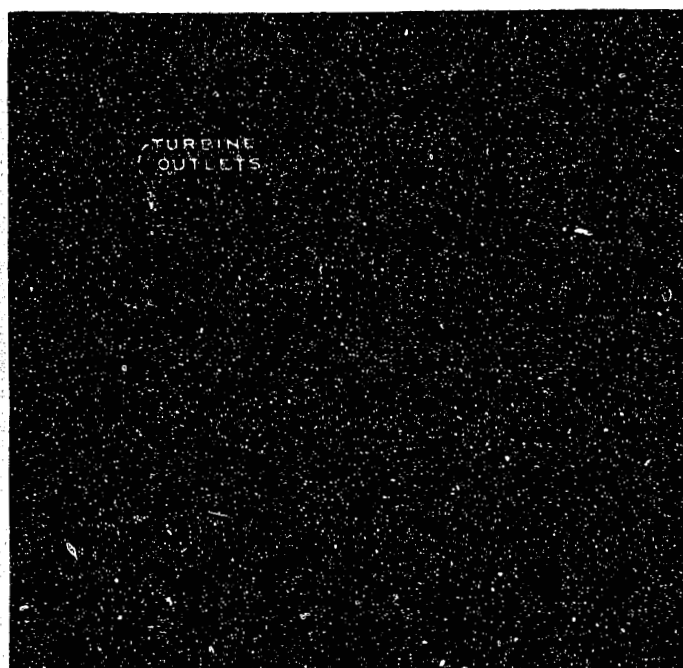


(B) Afterbay water surface with the maximum discharge of 604 cfs, minimum tailwater of 6580, and maximum head of 838 feet-8% air admitted to the absorber.

STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT
Afterbay Using Basin Without Baffles,
and With Sloping Floor at Downstream End.
1:9 Scale Model



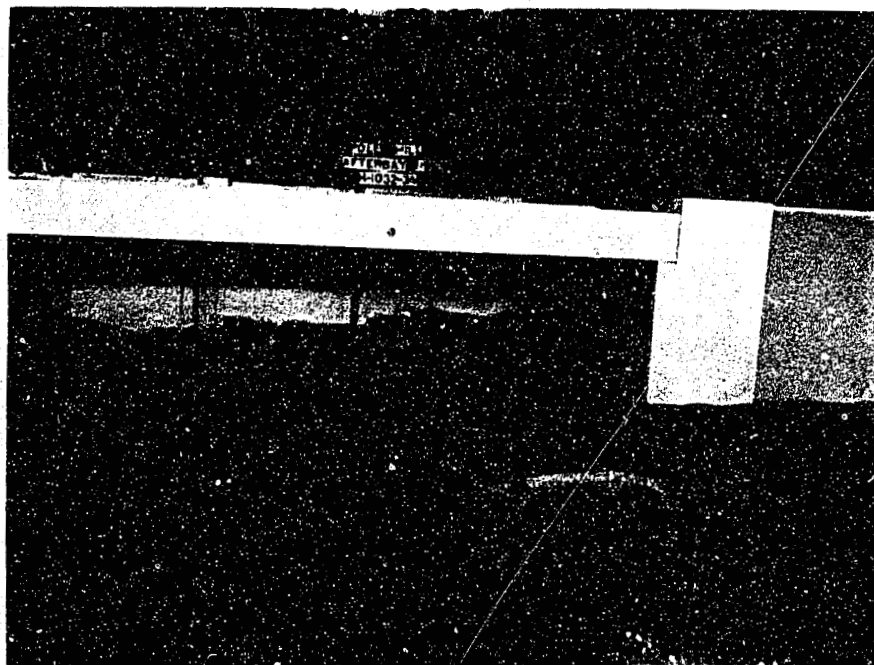
(A) Scour in $1\frac{1}{2}$ -inch gravel with the basin without baffles and with the sloping end.



(B) Scour in $\frac{1}{4}$ -inch pea gravel with recommended basin design

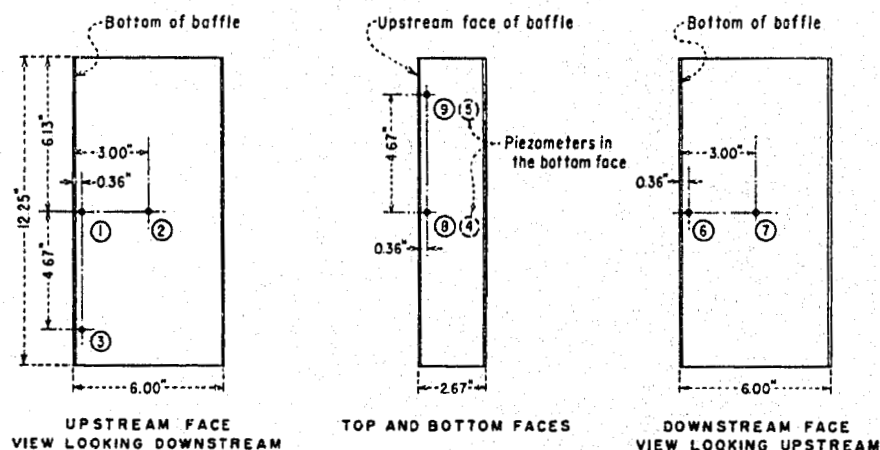
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT

Scour in Afterbay Channel After $2\frac{1}{2}$ Hours Operation With Maximum Discharge of 604 cfs, Minimum Tailwater of 6580.0, and Maximum Head of 838 Feet. 8% Air Admitted to Absorber
1:9 Scale Model



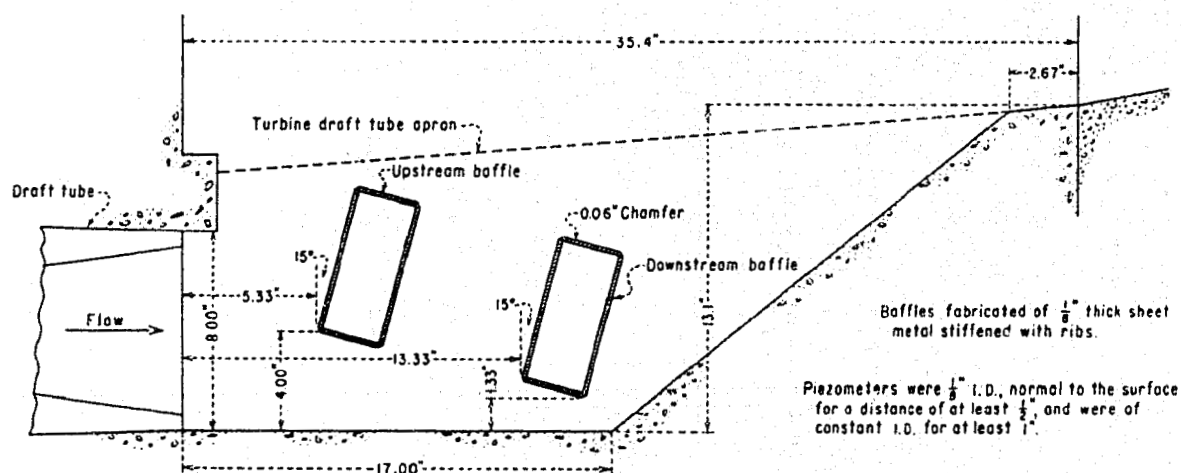
Afterbay water surface with maximum discharge of 604 cfs, normal tailwater of 6586.0, and maximum head of 838 feet. 8% air admitted to the absorber

STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT
Flow in the Afterbay With Recommended Stilling Basin Design
1:9 Scale Model



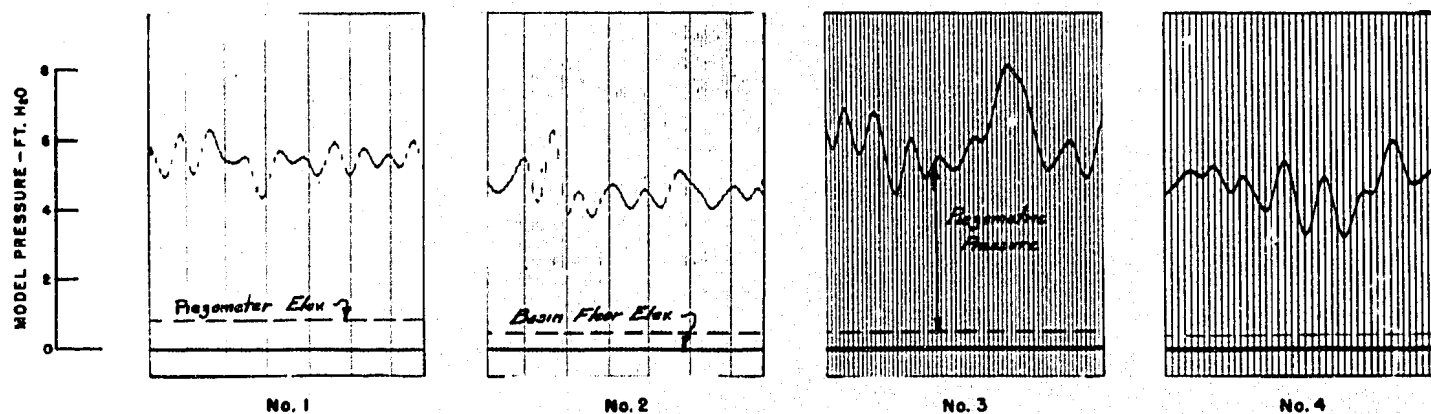
Note: Piezometers 11, 12, and etc. are in the downstream baffle in the same positions as piezometers 1, 2, etc.

A. LOCATION OF PIEZOMETERS IN THE BAFFLES

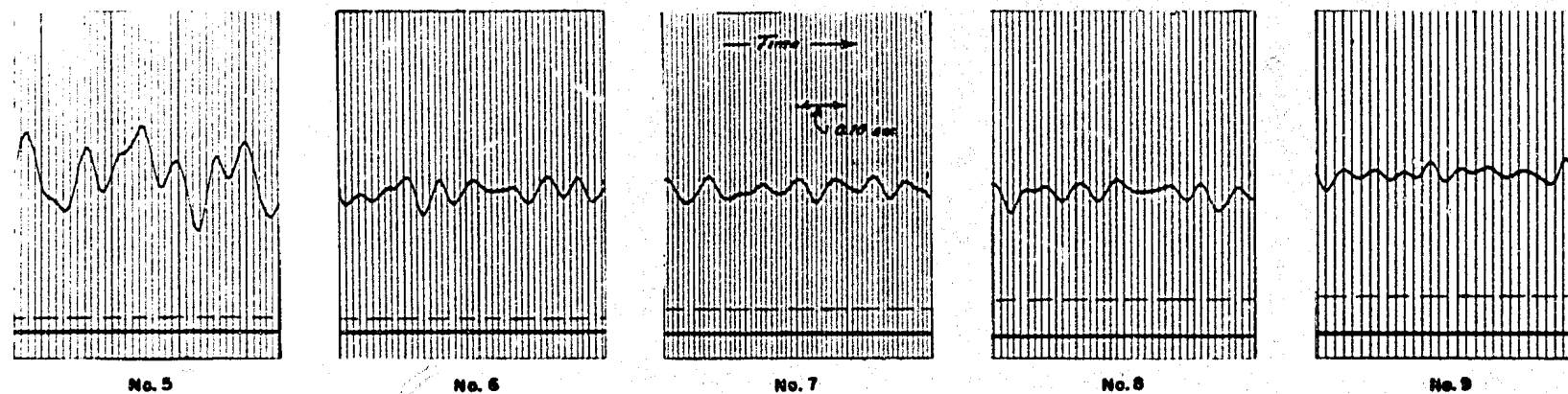


B. POSITION OF THE BAFFLES IN THE BASIN

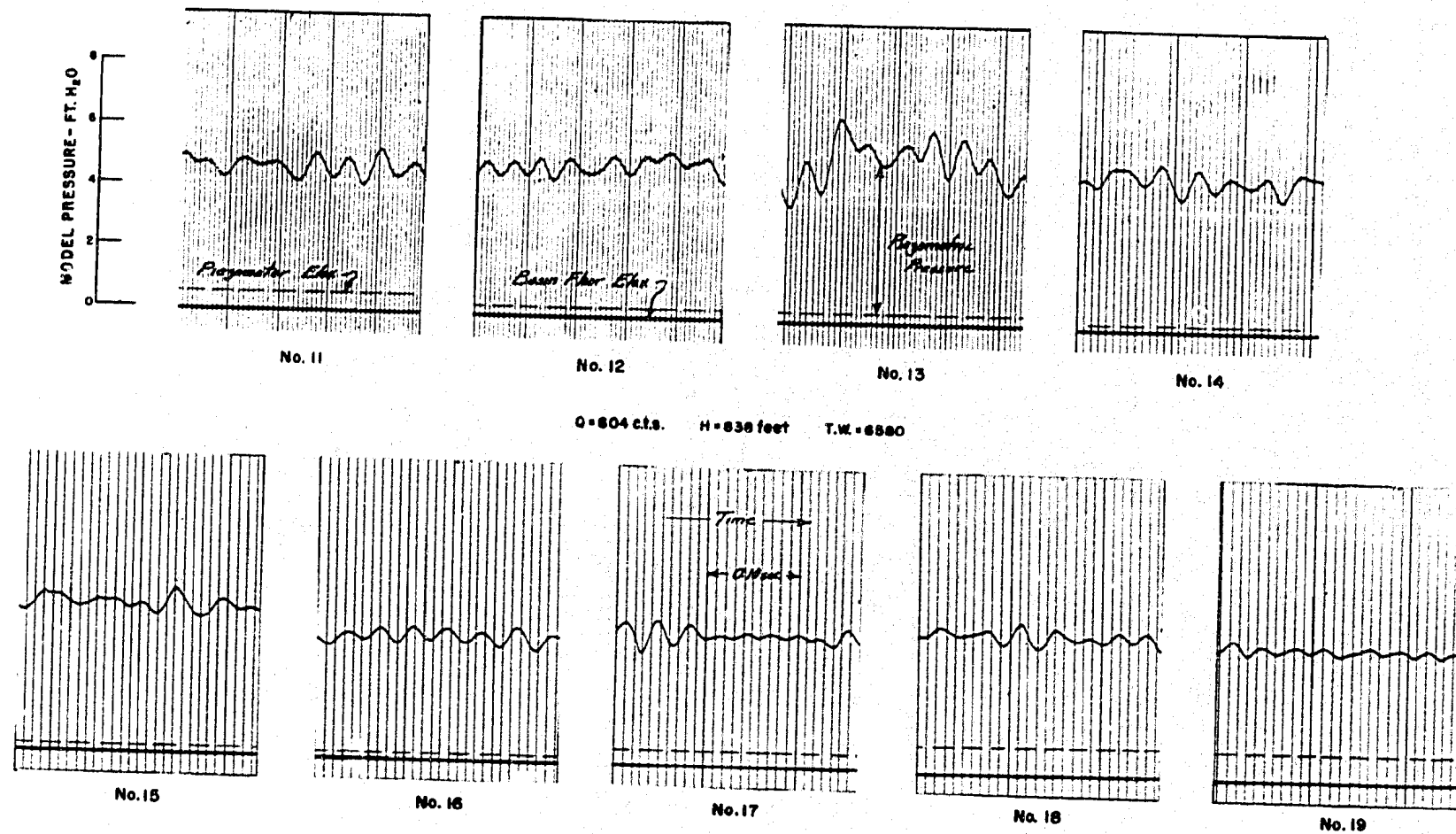
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBERS
POLE HILL AND FLATIRON POWER PLANTS
RECOMMENDED STILLING BASIN BAFFLES, AND LOCATION OF BAFFLE PIEZOMETERS
1:9 AND 1:88 SCALE MODELS



Q=604 cfs H=838 feet T.W.=6580

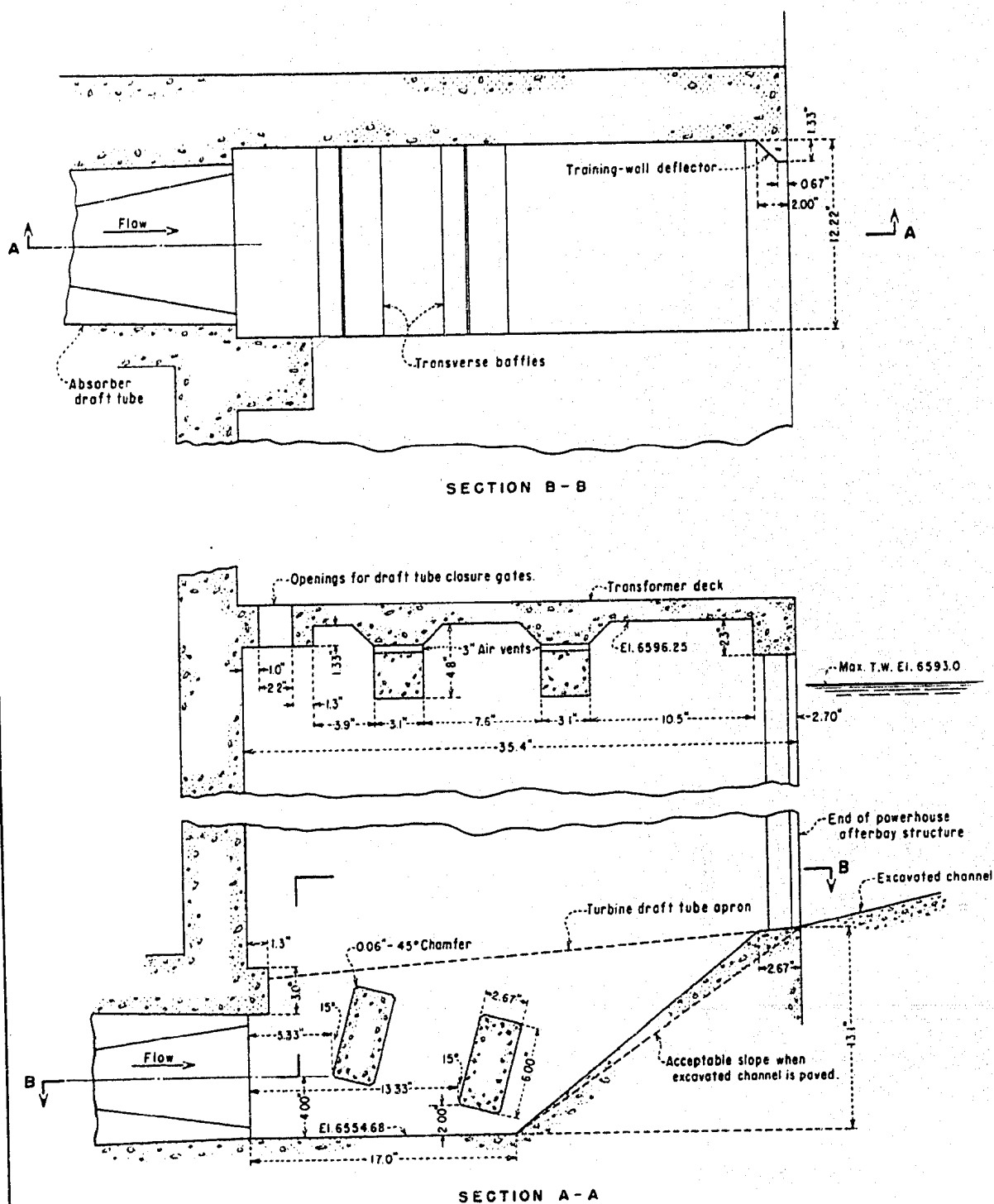


STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY & FORBER
POLE HILL POWER PLANT
PIEZOMETRIC PRESSURES ON THE UPSTREAM STILLING BASIN BAFFLE
1:9 SCALE MODEL



STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT
PIEZOMETRIC PRESSURES ON THE DOWNSTREAM STILLING BASIN BAFFLE
1:9 SCALE MODEL

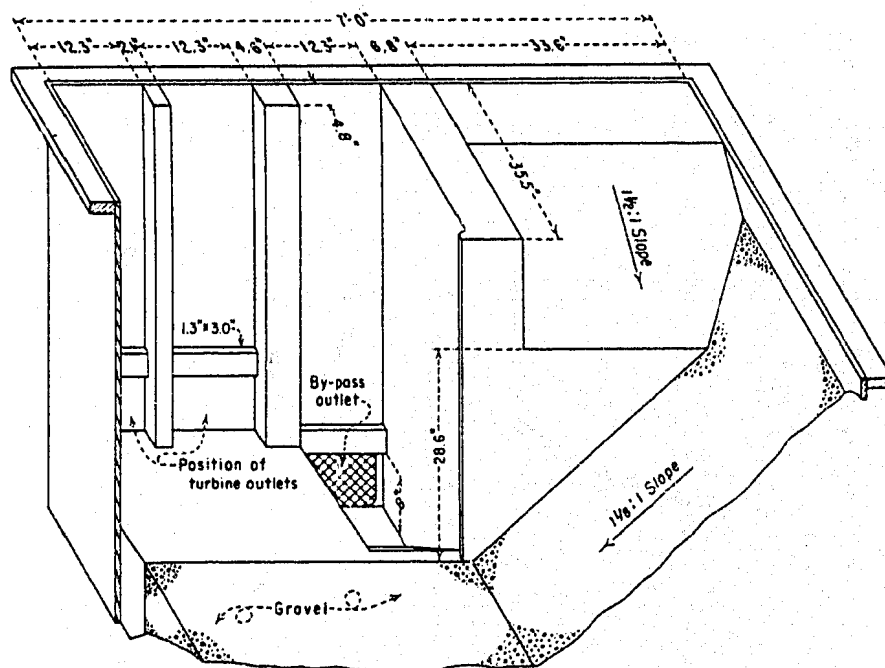
FIGURE 14
REPORT HYD. 353



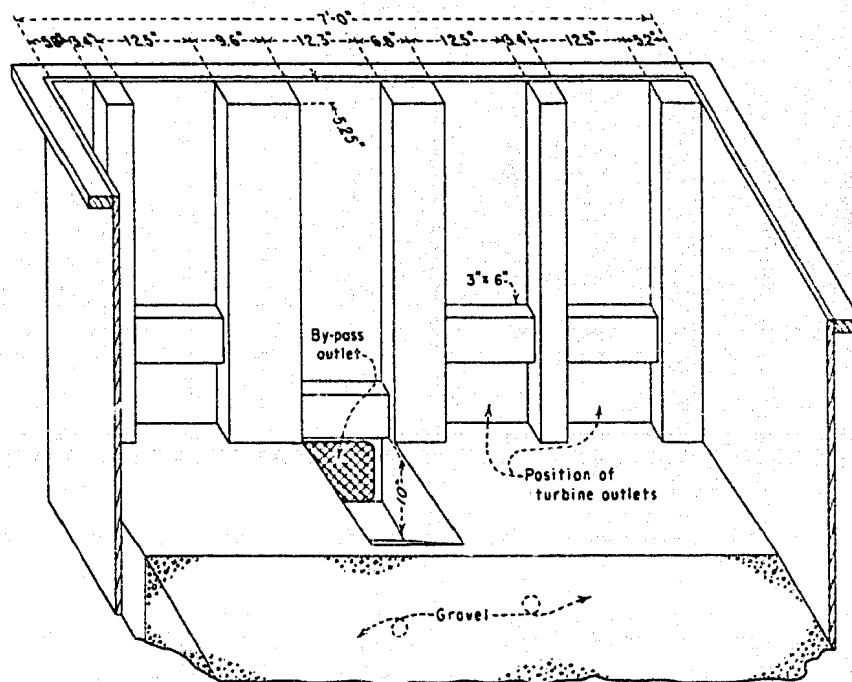
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER POLE HILL POWER PLANT

RECOMMENDED STILLING BASIN AND TRANSFORMER DECK

1:9 SCALE MODEL



A. POLE HILL AFTERBAY MODEL
1:9 SCALE

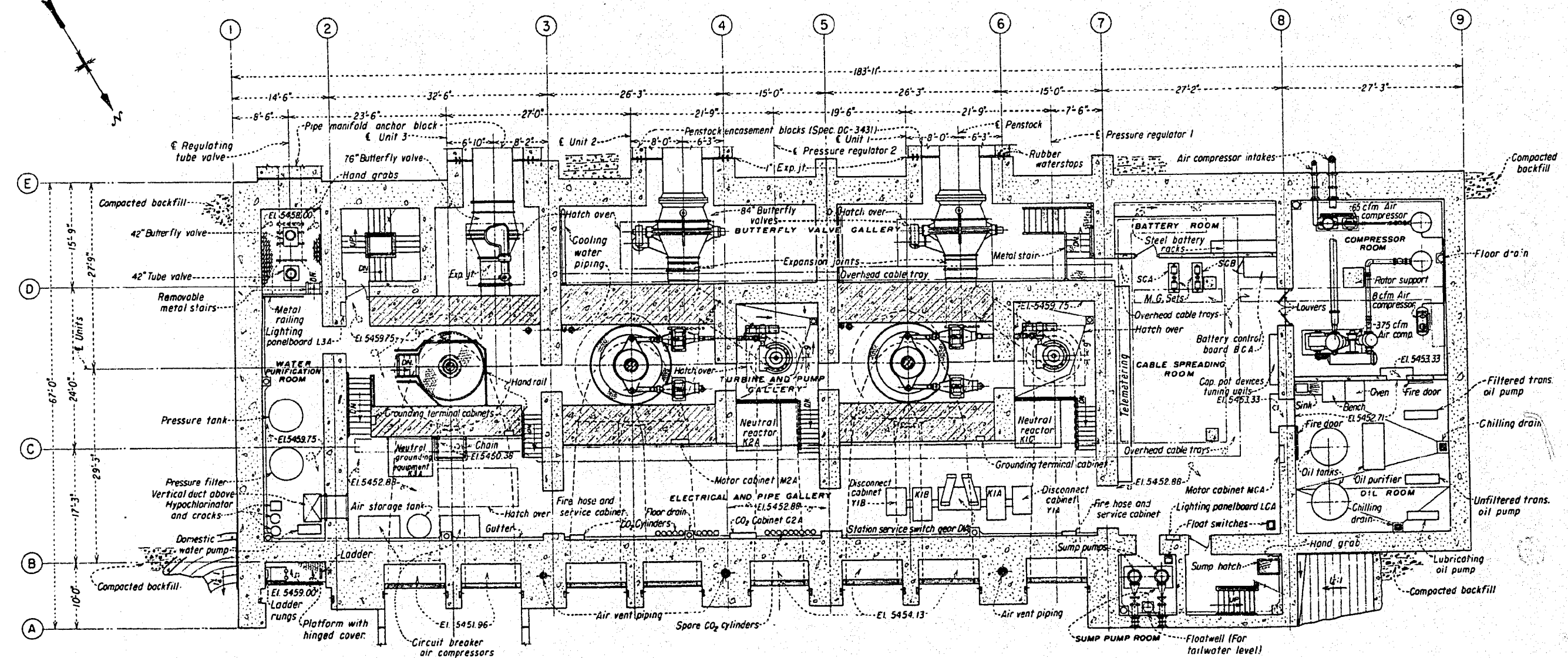


B. FLATIRON AFTERBAY MODEL
1:88 SCALE

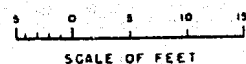
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBERS POLE HILL AND FLATIRON POWER PLANTS

MODIFICATIONS TO CHANGE 1:9 POLE HILL AFTERBAY MODEL
TO 1:88 FLATIRON AFTERBAY MODEL

FIGURE 16
REPORT HYD. 353



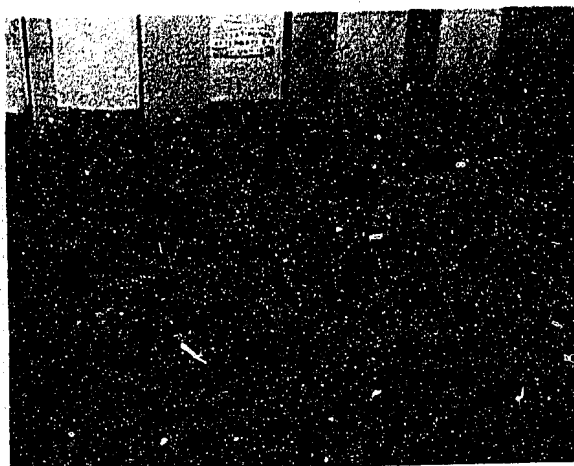
PLAN - EL 5459.75



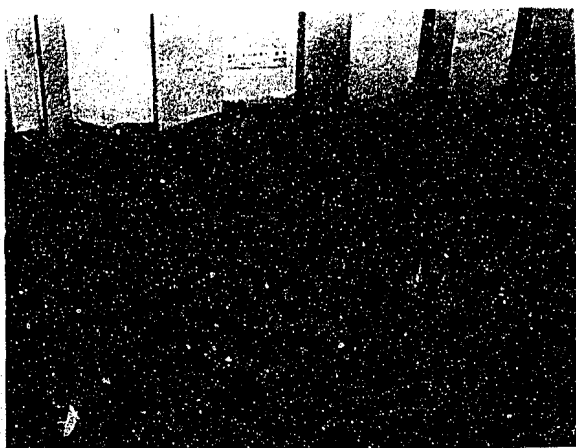
EXPLANATION

- First stage concrete
- Second stage concrete
- Concrete in blockouts

UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION COLORADO-BIG THOMPSON PROJECT - COLO.	
FLATIRON POWER AND PUMPING PLANT GENERAL ARRANGEMENT PLAN-TURBINE AND PUMP GALLERY-EL. 5459.75	
DESIGNED BY REVISED 12-27-51 BY CHECKED 2-9-52 BY	DRAWN BY SUBMITTED BY TRACED BY CHECKED BY APPROVED BY DENVER, COLORADO, NOVEMBER 30, 1950
245-D-5951	



(A) No Air



(B) 9% Air



(C) 18% Air

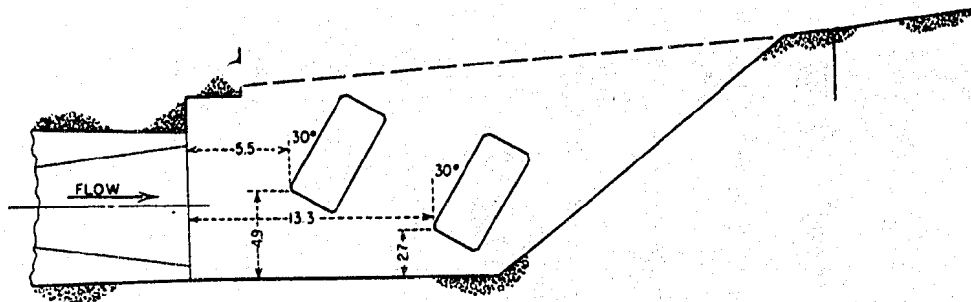
**STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
FLATIRON POWER PLANT**

**Effect of Quantity of Air Admitted to Absorber Upon Water Surface in
Afterbay - Recommended Basin Design**

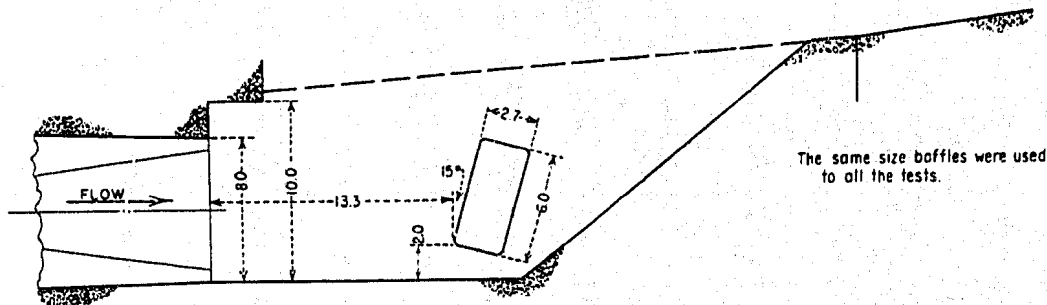
Q = 475 cfs

**H = 1055 feet
1:8.8 Scale**

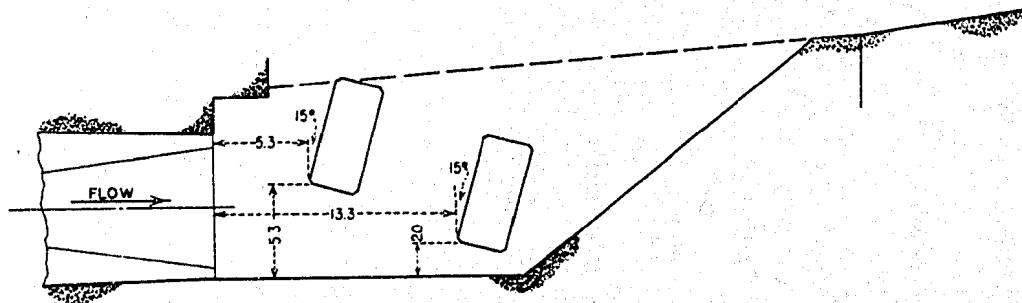
TW = 5462.0



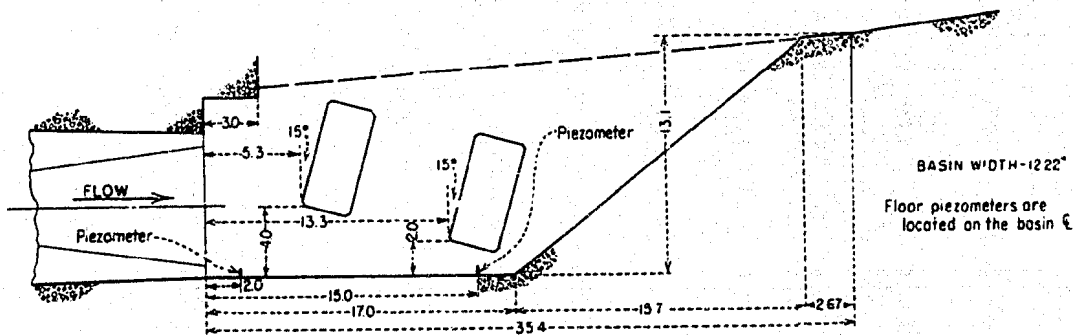
A. TWO BAFFLES INCLINED 30°



B. UPSTREAM BAFFLE REMOVED-DOWNSTREAM ONE INCLINED 15°



C. TWO BAFFLES INCLINED 15°-UPSTREAM ONE RAISED

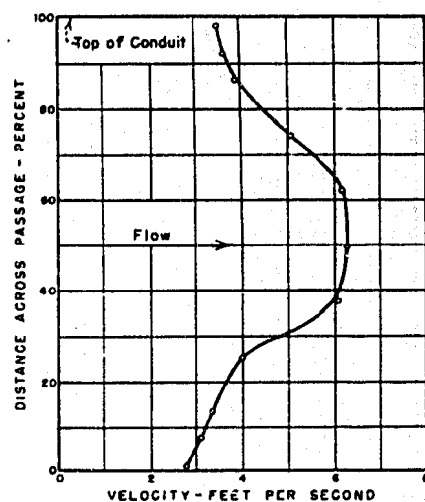


D. TWO BAFFLES INCLINED 15°-SIMILAR TO POLE HILL BASIN. RECOMMENDED DESIGN

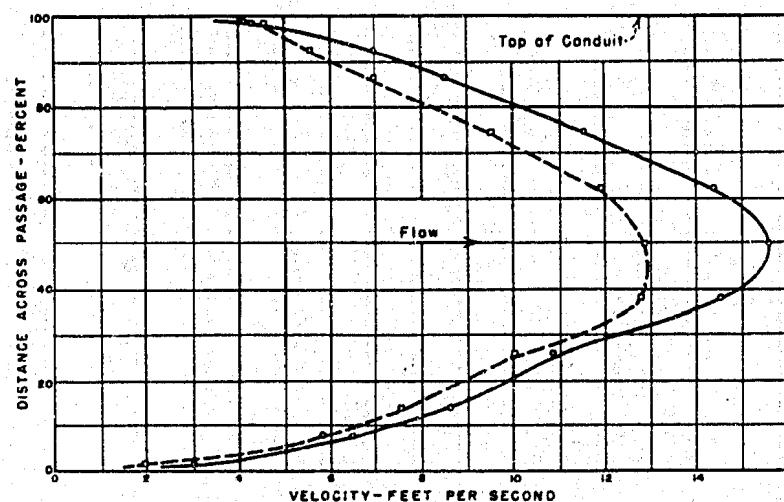
STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBERS
FLATIRON POWER PLANT

VARIOUS BAFFLE ARRANGEMENTS TESTED TO MINIMIZE UNDESIRABLE
EFFECT OF AIR ON AFTERBAY WATER SURFACE

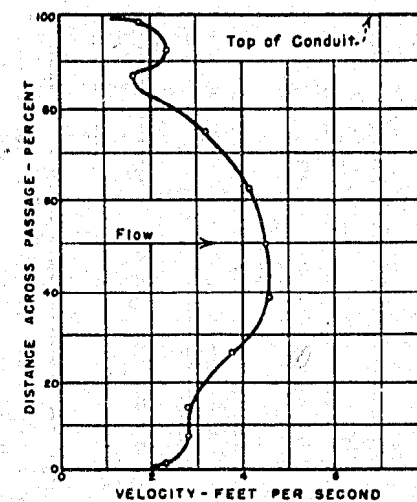
1.8.8 SCALE



A. LEFT TRAVERSE

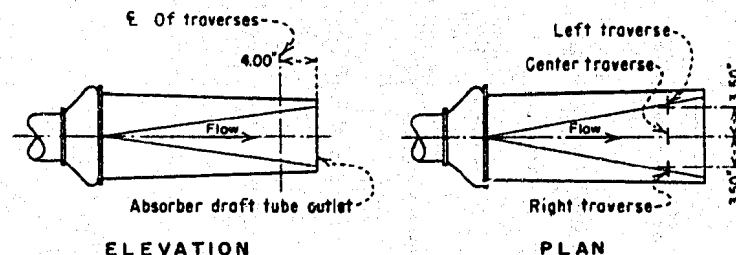


B. CENTER TRAVERSE



C. RIGHT TRAVERSE

—○— Full air admitted to absorber (8.3%)
- - -○- - - No air admitted to absorber

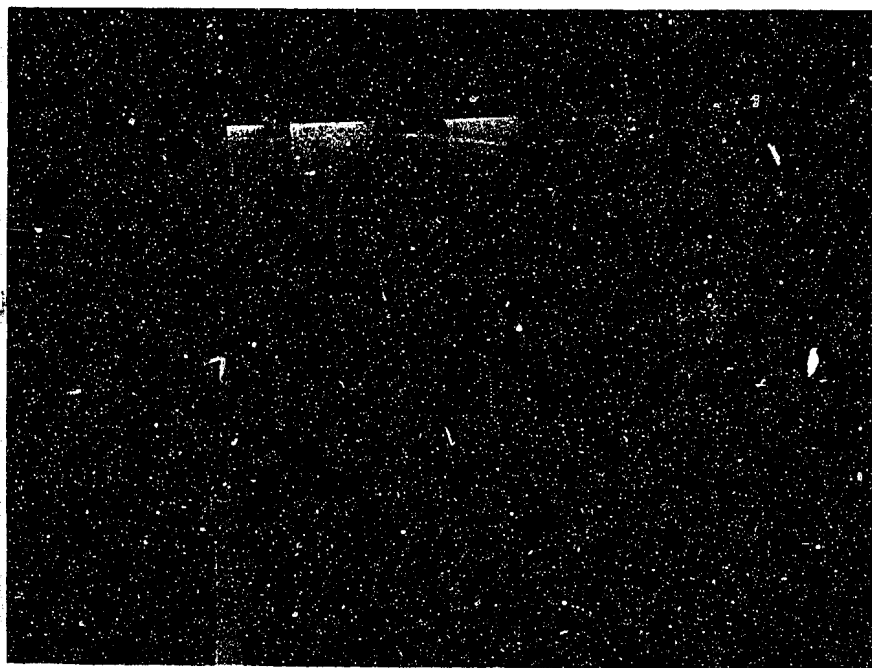


$Q = 604$ cfs (prototype)
 $H_T = 838$ feet (prototype)
 $T.W. = 6580.0$ feet (prototype)

STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
POLE HILL POWER PLANT
VELOCITY DISTRIBUTION AT THE EXIT OF THE STRAIGHT ABSORBER DRAFT TUBE
1:9 SCALE MODEL



(A) No Air



(B) 11% Air

**STILLING BASIN STUDIES FOR DISCHARGE FROM ENERGY ABSORBER
FLATIRON POWER PLANT**

Reduced Effect of Air Admitted to Absorber Upon Afterbay Water
Surface When Using Straight Absorber Draft Tube

$Q = 475$ cfs

$H = 1055$ feet

$TW = 5462.0$

1:8.8 Scale